CHRIS/PROBA data analysis at the Swiss Midlands Testsite

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Abstract: The spaceborne ESA-mission CHRIS/PROBA (Compact High Resolution Imaging Spectrometer-Project for On-board Autonomy) provides hyperspectral and multi-directional data of selected targets spread over the world. This coupled system represents a new source of information for Earth observation purposes. While the spectral information content of CHRIS data is able to assess the biochemistry of a vegetation canopy, the directional information can describe the structure of an observed canopy. Both biochemical content and canopy structure change with phenological development. During May to September 2005, numerous spectro-directional CHRIS data sets for six different phenological stages were acquired over the recently established Swiss Midlands Testsite. The area covered is dominated by agricultural fields and forests. A selection of CHRIS data sets that span the observed growing phase were geometrically and atmospherically corrected using a parametric geocoding approach and the physically based atmospheric correction software ATCOR. The analysis of the CHRIS data focuses on the interpretation of HDRF (Hemispherical Directional Reflectance Factor) changes contained in the various data sets over time. The spectrodirectional behaviour of agricultural crops varies over time as a function of vegetation stages (phenology). Understanding of this effect, which is studied on selected crops, may improve agricultural monitoring and crop classification. Accurate spatial mapping of crop status serves as an important input to precision agriculture.

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ABSTRACT

The spaceborne ESA-mission CHRIS/PROBA (Compact High Resolution Imaging Spectrometer-Project for On-board Autonomy) provides hyperspectral and multi-directional data of selected targets spread over the world. This coupled system represents a new source of information for Earth observation purposes. While the spectral information content of CHRIS data is able to assess the biochemistry of a vegetation canopy, the directional information can describe the structure of an observed canopy. Both biochemical content and canopy structure change with phenological development. During May to September 2005, numerous spectro-directional CHRIS data sets for six different phenological stages were acquired over the recently established Swiss Midlands Testsite. The area covered is dominated by agricultural fields and forests. A selection of CHRIS data sets that span the observed growing phase were geometrically and atmospherically corrected using a parametric geocoding approach and the physically based atmospheric correction software ATCOR. The analysis of the CHRIS data focuses on the interpretation of HDRF (Hemispherical Directional Reflectance Factor) changes contained in the various data sets over time. The spectrodirectional behaviour of agricultural crops varies over time as a function of vegetation stages (phenology). Understanding of this effect, which is studied on selected crops, may improve agricultural monitoring and crop classification. Accurate spatial mapping of crop status serves as an important input to precision agriculture.

INTRODUCTION

A) Research Goals at the Swiss Midlands Testsite

The Swiss Midlands Testsite has been established in 2005 as a second CHRIS/PROBA acquisition site in Switzerland beside the already existing Swiss National Park Testsite [1]. Research goals at the Swiss Midlands Testsite are defined in the domains of agriculture and forestry. For the agricultural part, the spectro-directional information content of multitemporal CHRIS data is addressed. The spectro-directional behaviour of crops varies over time as a function of vegetation stages (phenology). Concerning the forestry part, the question whether multi-angular data improves biochemistry retrieval is investigated. It is also tested, if certain view angles emerge to be superior for forest biochemical retrieval. However, in this paper, only results from the agricultural part of the study activities are presented. First results related to the forestry part are reported elsewhere [2].

B) Background ot Data Analysis Related to Agriculture

The reflectance of a vegetation canopy is known to be primarily a function of the foliage optical properties, the canopy structure, the illumination conditions and the viewing geometry. Multiangular measurements have shown the potential to distinguish different land cover and surface types of different structural characteristics [3]. Such observations of reflectance anisotropy are helpful to complement the spectral measurements for a complete and robust characterization of a vegetation canopy [1]. The CHRIS instrument observes the canopy reflected radiance in the spectral, directional and spatial dimensions, thus describing the canopy reflectance based on independent but complementary information sources. The information contained in spectrodirectional measurements of agricultural fields is crop specific and varies over time as a function of phenology. Physical properties and geometrical arrangements of the elements that constitute the terrestrial

surfaces largely control the directional pattern of solar radiation scattered by vegetation in the red spectral domain [4][5]. The degree of anisotropy has been shown to be related to canopy structure and subpixel heterogeneity, and can be described e.g. by the Minnaert function parameter *k* in the parametric RPV model [6]. The so called bell-shaped Bidirectional Reflectance Factor (BRF) patterns can be associated to heterogeneous canopies of medium density over a bright background. A bell-shaped BRF pattern is caused by the relative contribution of uncollided radiation from the bright background for close to nadir observations. Conversely, homogeneous or closed vegetation canopies develop a bowl-shaped pattern instead, provided background brightness is sufficiently low [4]. The HDRF as observed by CHRIS and the BRF as used in theory are here assumed to be comparable. Due to phenological changes, HDRF patterns of agricultural stands are subject to alter with time and can thus be monitored from space.
In this study we propose to assess the spectrodirectional information contained in a multitemporal set of CHRIS data that were acquired over an agricultural area in Switzerland. CHRIS provides the unique opportunity to monitor crop status from spaceborne spectrodirectional data. Such information can serve as an important input to precision agriculture.

DATA

A) Test Site and Field Data

The test site for this study is located in Central Switzerland (7°53' E, 47°16'N, see Fig. 1). The hilly area is dominated by agricultural fields in the lower parts (450-500 m a.s.l.) and mixed forests mainly on the hilltops (elevations up to 700 m a.s.l.). Agriculture concentrates on barley, wheat, maize, sugar beet and pasture land. CHRIS multiangular data sets were acquired over the test site on eight different dates between 26 May 2005 and 22 September 2005 in Mode 5 (see Tab. 1). Out of this data sets, four dates that represent major steps in phenology of the selected agricultural fields were selected for further processing and data exploitation. The selected dates are 26 May 2005, 20 June 2005, 17 August 2005 and 22 September 2005. Information concerning the individual viewing geometries of the selected data sets is given in Tab. 2. It can clearly be seen from this table, that the nominal fly-by zenith angles (FZA) of the CHRIS data acquisitions do rarely represent the actual viewing geometry for the dates under investigation. Especially the observation zenith angles for nadir view (FZA = 0°) show considerable deviations, which have to be accounted for in subsequent geometric and atmospheric correction.

Table 1: CHRIS specifications for Mode 5.

Spatial Sampling	Image area	View angles	Spectral bands	Spectral range
17m @ 556 km altitude	6.5x13 km (372x748 pixels)	5 nominal angles @ +55°, +36°, 0°, -36°, -55°	37 bands with 6-33 nm width	447-1035 nm

Table 2: CHRIS image acquisition geometry [°] for the scenes under investigation (negative values for backscatter angles).

		FZA +55°	FZA +36°	FZA 0°	FZA -36°	FZA -55°	Solar zen./az.
26/05/05	Obs. Zen.	50.61	29.70	-8.83	-34.65	-54.01;	-27.10 162.94
	Obs. Az.*	187.35	79.91	44.82	24.68	20.26;	
20/06/05	Obs. Zen.	54.08	31.89	-3.90	-37.43	-57.25;	-25.37 157.26
	Obs. Az.*	192.90	192.50	22.32	14.37	14.37;	
17/08/05	Obs. Zen.	50.82	34.59	-24.79	-38.12$^+$	-53.52	-35.88$^+$ 153.31$^+$
	Obs. Az.*	209.40	218.8	316.56	337.28$^+$	350.79	

22/09/05	Obs. Zen.	52.97	33.29	16.70	-37.95	-56.27	-46.90 171.70
	Obs. Az.*	181.80	168.82	135.06	31.84	25.25	

**sensor to target direction,   ; agricultural test sites not covered,   +"hot spot" constellation*

Ground truth data were collected in parallel to the CHRIS data takes on most dates. Data collection for selected agricultural stands included spectroradiometric measurements using a FieldSpec Pro FR, LAI measurements using a Licor LAI-2000 Plant Canopy Analyzer and hemispherical photographs, as well as determination of leaf water content in the laboratory and SPAD chlorophyll values. The land use type was recorded for a large number of agricultural fields.

B) Geometric and Atmospheric Processing

Geometric and atmospheric correction of the multiangular CHRIS data sets under investigation were performed following an approach described in [7]. Geocorrection is therefore based on a 3D physical model developed by Toutin [8] which is implemented in the commercially available image processing software PCI/Geomatica. High locational accuracy of the respective multiangular products after geometric correction is a prerequisite for reliable retrieval of HDRF information from the data set. The root mean square errors (RMSE) for the specific region of interest do generally not exceed one pixel. Fig. 1 shows a subset of a geocorrected CHRIS nadir scene for the specific region of interest in this study. The accuracy of the geocorrection may be seen from the overlying pixelmap. Subsequent atmospheric correction of the CHRIS radiance data products was performed using ATCOR-3 [9], which is based on MODTRAN-4. ATCOR-3 accounts for terrain effects by incorporating DEM data and their derivatives such as slope and aspect, sky view factor and cast shadow. ATCOR-3 is capable of processing data from tilted sensors by accounting for varying path lengths through the atmosphere and varying transmittance. Atmospheric correction results in the generation of HDRF (Hemispherical Directional Reflectance Factor) data sets for the various CHRIS view angles.

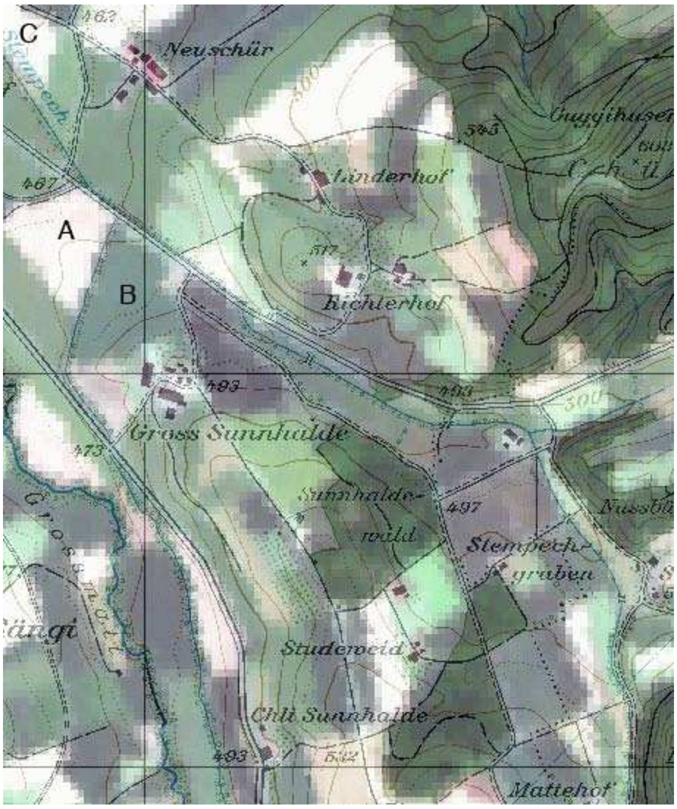

Figure 1: Geocorrected subset of the 26 May 2005 CHRIS nadir scene for the region of interest in this study with overlying pixelmap (1:25'000, © swisstopo). The investigated agricultural fields are: A maize, B winter barley and C sugar beet.

The following considerations on vegetation growth from multiangular and multitemporal CHRIS data are based on a specific maize (A), winter barley (B) and sugar beet (C) field.

RESULTS

Monitoring agricultural stands over time by means of a spectrodirectional sensor allows the spectral, directional and temporal dimension to be addressed. While the spectral information contained in Earth Observation data is based mainly on absorption features related to the biochemistry of the vegetation, multiangular measurements can characterize the surface reflectance anisotropy, which is diagnostic for vegetation structure. The temporal dimension, finally, reveals dynamics that are linked to plant evolution and physiological processes [10].

A) Temporal Changes in Canopy Reflectance

Fig. 2 and Fig. 3 show the development stages for maize and winter barley as they were observed on specific dates of CHRIS data acquisitions in 2005. The respective phenological stages are described in Tab. 3. The canopy reflectances (HDRF) that were measured by CHRIS can be seen in Fig. 4. They represent the spectral changes in nadir direction (FZA = 0°) of the cultivars due to their phenological development over time.

Table 3: Phenological stages of the observed maize and winter barley fields
for corresponding CHRIS acquisitions.

Date	Phenological Stage Maize	Phenological Stage Winter barley
26 May 2005	Bare soil	Late boot stage (DC 47-49)+
20 June 2005	Eight leaves stage (vegetative)	Medium Milk (DC 75)+
15 July 2005*	Differentiation of flowers (reproductive)	Caryopsis hard (DC 91-92)+
17 August 2005	Flowering (reproductive)	Bare soil
22 September 2005	Corn development (Maturation)	Grass

*CHRIS data not included in this study, +Decimal code by Zadoks [11]

Figure 2: Phenological stages of the observed maize field (ul: 26/05/2005, ur: 20/06/2005, ll: 15/07/2005, lr: 17/08/2005, no photograph on 22/09/2005).

Figure 3: Phenological stages of the observed winter barley field (ul: 26/05/2005, ur: 20/06/2005, lr: 17/08/2005, no photograph on 22/09/2005).

The phenological development of maize, covering stages of the vegetative, reproductive and maturation phase, are given in Fig 4 (left). For winter barley, evolution stages of the vegetative and reproductive phase, as well as post-harvest situations can be seen in Fig. 4 (right).

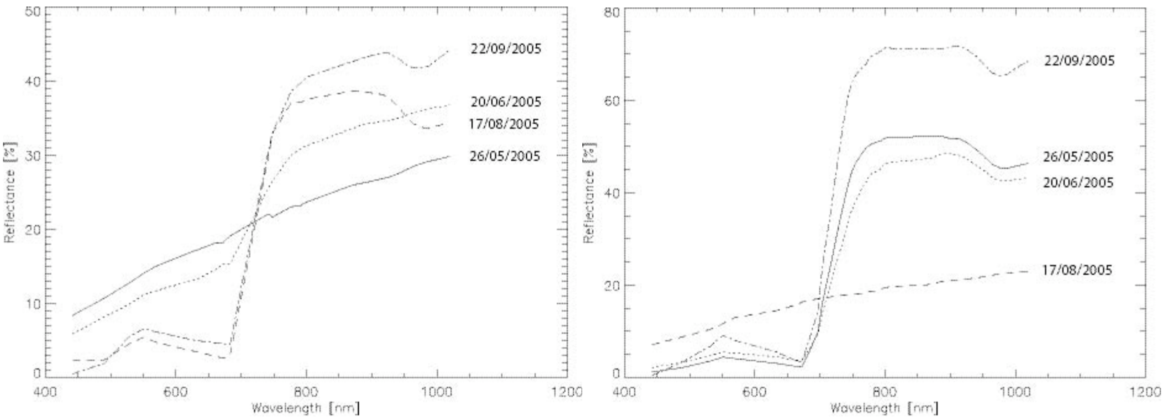

Figure 4: Canopy reflectances (HDRF) from CHRIS nadir view (FZA = 0°) on dates under investigation for maize (left) and winter barley (right), which followed by grass on 22 September 2005.

B) Multiangular Behaviour of Canopy Reflectance

As the CHRIS sensor offers the unique possibility to acquire multiangular data sets, the effect of angular reflectance anisotropy and its potential for vegetation structure differentiation is addressed in this study. Qualitative interpretation of the CHRIS HDRF data in Fig. 5 shows for both maize and winter barley an increase in reflectance in backscatter direction, i.e., for FZA = -36° and FZA = -55°.
Depending on the solar zenith and therefore the position of the “hot spot”, either FZA = -36° or FZA = -55° shows maximum reflectance values in the red domain. FZA = +36° and FZA = +55° look towards the sun (forward scatter direction) and are thus darker, as described in [12].

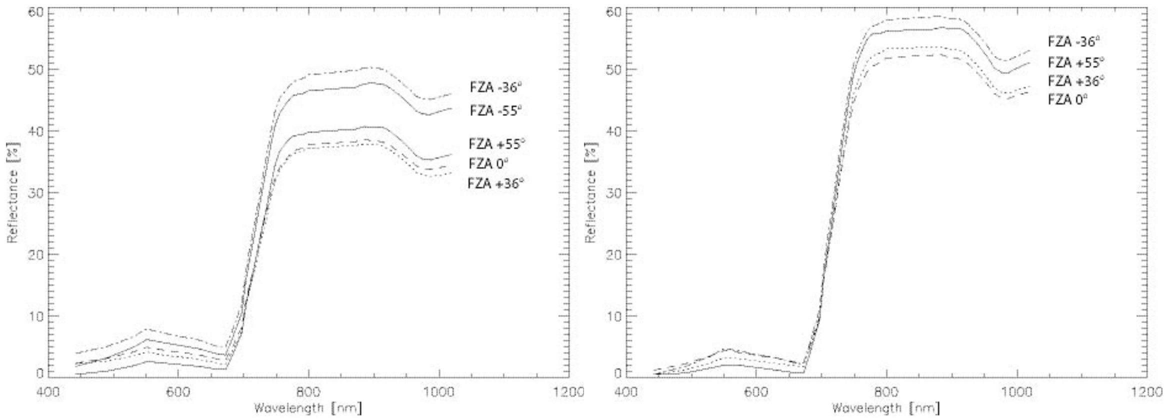

Figure 5: HDRF data for maize on 17 August 2005 (left) and winter barley on 26 May 2005 (right) obtained by CHRIS for five (four in the case of winter barley) FZA. Positive values of FZA are forward scatter viewing directions, negative values are view angles in backward scatter direction.

The directional behaviour at 672 nm (red domain) of maize and winter barley is given in Fig. 6 and for sugar beet in Fig. 7 for the four selected dates of CHRIS acquisitions during 2005. In these graphs, the actual view zenith angles are plotted instead of the nominal FZA. Due to their observed discrepancies, it is important to use the true view zenith angles of CHRIS to properly assess specific HDRF patterns of surface types. It is clearly visible from all three plots, that the 17 August 2005 sun/sensor constellation observes a close to "hot-spot" situation for FZA = -36° (solar and sensor zenith differ by 2.24°, solar and sensor azimut by 3.79°), which results in an obvious reflectance maximum for this view angle. In general, bare soils can be characterized by a linear increase of reflectance from forward scatter directions (positive FZA) to backscatter situations where the sun is situated in-line with the sensor (e.g. maize and sugar beet on 26 May 2005). Trends towards bell-shaped HDRF anisotropy with phenological development may be seen for canopies with medium density and thus still visible background contribution, being in good agreement with theory. However, more phenological stages and complete CHRIS data sets of five view angles would be needed to confirm these trends.

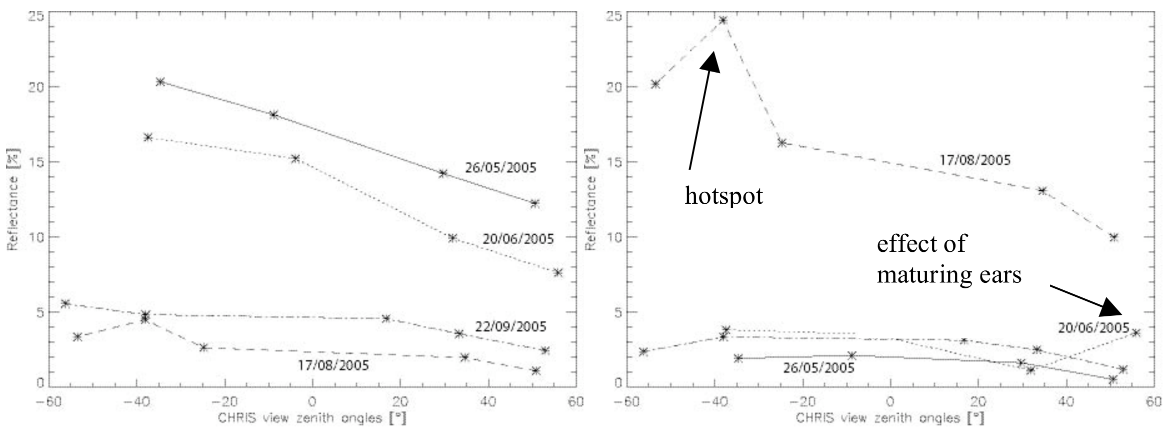

Figure 6: Multiangular and multitemporal HDRF patterns measured with CHRIS at 672 nm (red domain) for maize (left) and winter barley (right).

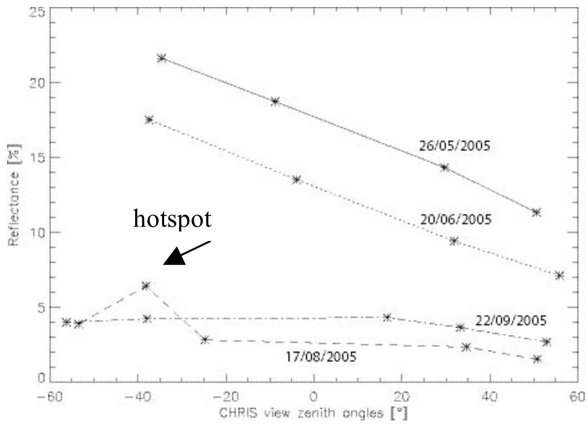

Figure 7: Multiangular and multitemporal HDRF patterns measured with CHRIS at 672 nm (red domain) for sugar beet.

HDRF data of winter barley on 20 June 2005 show an untypical increase in reflectance for FZA = +55° (see Fig. 6, right). This is possibly due to the strong spectral influence of maturing ears at this phenological stage. The spectral contribution of the ears becomes more dominant at large observation zenith angles, as can be seen in Fig. 3 (upper right image). A comparable effect is reported in [12] for flowering maize.

CONCLUSIONS

This study demonstrated that phenological development of agricultural crops can successfully be monitored using spectrodirectional and multitemporal CHRIS/PROBA data. Accurate geometric and atmospheric preprocessing of the numerous data sets is an important prerequisite. As the CHRIS sensor provides multiangular data sets, the reflectance anisotropy of selected crops could be assessed. Typical directional patterns of HDRF in the red domain were found for bare soil and heterogeneous canopies of medium density over a bright background (slight trends towards bell-shaped anisotropy), depending on phenological stages. However, these patterns may be disturbed by a) close-to-hot spot constellations, b) deviations from nadir view for FZA = 0° and c) individual plant parts (e.g., ears).
The potential to distinguish different land cover and surface types of different structural characteristics related to phenology is clearly identified by the use of multiangular data. The temporal evolution of the Minnaert function parameter *k,* retrievable by the RPV model, is subject to future studies. Improved techniques to assess crop status are important in precision agriculture. The study of spectrodirectional patterns of HDRF over time could largely benefit from reduced mispointing errors of CHRIS at large off-nadir angles and from further data of other phenological stages.

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